Draft Plan for Scintillator Mixing at FNAL

Dave Pushka, 14 October 2005

The NOvA off axis experiment is designed to use liquid scintillator contained in PVC extrusions. The liquid scintillator is made from three components: Mineral Oil (approximately 90% by volume), pseudocumene (approximately 10% by volume) which is the component that emits light when energy is deposited in the molecule, and wave shifters. The wave shifters absorber light emitted from the pseudocumene and re-emit light in at a longer wave length which is better matched to the wave length where the photo-detector device is sensitive. A number of specific chemicals can be used as wave shifters and the NOvA scintillator will likely use a mixture of at least two. The wave shifters are a fine, dry powder which is dissolved into the pseudocumene. These powders will not dissolve into mineral oil. Once the pseudocumene and the wave shifters are combined, the mixture is diluted with mineral oil. Clarity (measured by the attenuation length) of the mineral oil is very important as any opacity will reduce the light available to be detected by the photo-detector.

Blending of the raw ingredients represents the key manufacturing step for the scintillator. Several procurement options are possible including purchasing a fully mixed and blended scintillator fluid, purchasing the raw ingredients and contracting with an outside firm to perform the blending, and purchasing the raw ingredients and mixing the scintillator using laboratory staff and facilities (home brew). Purchasing fully mixed and blended scintillator is believed to be cost prohibitive due to the lack of a competitive marketplace. Contract blending has been investigated, but the costs remain significant. Understanding the process of mixing scintillator in a home brew option would both provide the basis of a cost estimate and the insight necessary to write a specification should the laboratory pursue the contract blending option.

A first pass draft plan for home brew mixing of the scintillator is as follows. Several options are presented, each representing modifications to the first option.

Option 1:
Receive standard 20,000 gal capacity Rail Cars. Pick a suitable number of rail cars and set the quantities delivered in each rail car so that one railcar of pseudocumene will be used to top off ten rail cars of mineral oil. Therefore, the mineral oil rail cars must be filled to less than 90% of the allowable maximum fill capacity.

Number of Rail Cars of Pseudocumene	40	
Number of Rail Cars of Mineral Oil	400	
Fill each pseudocumene rail tank car to:	17,933	gallons
Fill each mineral oil rail tank car to:	16,515	gallons

Receive the wave shifting dry powder in a finite number of packages, ideally so that one package of dry powder is sized to mix with one rail car of pseudocumene.

Total amount of wave shifting dry powder used:	60,000	kilograms

Number of Pounds of Wave shifting dry powder	132,240	pounds
Wave shifters packaged in bundles of:	3,306	pounds
Number of wave shifter packages:	40	

Assume the purchase order to the mineral oil, pseudocumene, and wave shifter powder vendors specifies the materials are delivered in the above quantities. Some immediate questions are:

1. How precisely would the vendor fill the shipping containers to the specified volume or weight?
2. If the bills of lading for mineral oil said 16,515 gallons, how much mineral oil would actually be loaded in the rail car?
3. If the customer (Fermilab) were to perform a quality assurance function and measure the volume of fluid in the rail car, would one get a precise number by weighing the car, subtracting the tare weight, and dividing by the density measured from a sample?
4. If the answer to the above question is yes, would equipment like http://www.scalesales.com/railweighing.htm provide a precision weight to 1%.

Assume in car mixing of wave shifters and pseudocumene. Use a loading arm to transfer the dry powders (physically similar to powder sugar) from the wave shifter delivery container to the top of the pseudocumene rail car. An example of a loading arm is: http://www.fmctechnologies.com/upload/top_open_dome_loaders__47ko.pdf

Mix well in the rail car using in tank mixing equipment. There are several styles of in tank mixing equipment. The first type includes shaft driven propellers that induce fluid motion to cause mixing. Some examples are shown here:
http://www.emimixers.com/products/tank_car_mixers/ or
http://www.capitalprocess.com/emi-cleveland.htm
Other kinds of mixers include ones that use bubbles of dry gas injected to the bottom of the tank to induce mixing. See: http://www.pulsair.com/bubbpwr1.html. This type of equipment would have the potential problem of releasing pseudocumene vapor laden air from the top of the railcar. Perhaps passing the air thru a charcoal filter would be sufficient to reduce fugitive emissions. Perhaps this makes for more emissions than is necessary.

A third type of mixer is the Ejector type mixture:
http://www.severntrentservices.com/water_purification/disinfection_products/eductors/tank_mixing_eductors/applications.jsp) or
http://www.vortexventures.com/Products/RadialEductors/RadialEductorsS.htm .
To use one of these, product would be pumped thru the ejector. Perhaps the pump could be a submersible pump or perhaps an external self-priming unit.

More Questions:

5. What type of mixing equipment would be recommended to blend the dry wave shifting powders into the pseudocumene?
6. How long does it take to mix the components to reach a homogeneous mixture?
7. Do the wave shifting powders dissolve in the pseudocumene or are small particles held in suspension? If they are held in suspension, will they settle out once the agitation ends?

Once the wave shifting powder is completely mixed (dissolved?) into the pseudocumene, the rail car contents would be:

Weight of Pseudocumene in rail car	131,643	pounds
Weight of waver shifters in rail car	3,306.0	pounds
Total weight of mixed material in rail car	134,949	pounds
Weight fraction of wave shifters in pseudocumene mix	0.024498	
Weight fraction of pseudocumene in mix	0.975502	

At this step, it would be prudent to sample the mixture and confirm that the proper concentration of wave shifter is present in the mixture. Therefore, test mixture and adjust the mixture as required. Adjustments would be to add additional pseudocumene to dilute the mixture or additional wave shifters to strengthen the mixture.

Once the mixture was shown to be fully satisfactory, the contents of the pseudocumene / waver shifter mix rail car can be added to the mineral oil.

Receive a rail car of Mineral Oil filled to:	16,515	gallons
Transfer this quantity of Pseudocumene w/ wave shifter compound to Mineral Oil already in a rail car:	1,835	gallons
Total Volume of Mineral Oil and pseudocumene in Rail Car:	18,350	gallons
Fraction pseudocumene:	0.100	
Fraction Mineral Oil:	0.900	
Pounds of Wave shifters in rail car oil and pseudocumene mix	330.60	pounds

More Questions:

8. Is the accuracy of inline flow measurement equipment of sufficient accuracy to measure 1835.0 gallons of pseudocumene and wave shifter mix to the 1% level?
9. Alternatively, would it be better to use a batch mix? For example, draw off the appropriate quantity of pseudocumene into a container of known volume, and then transfer the entire contents of the container into the mineral oil rail car.
10. For quality control, would it be reasonable to draw off a batch, measure the batch light output, and either dilute the mixture with mineral oil or strengthen the mixture with pseudocumene / wave shifter?

Empty Rail Car into this number of over-the road trucks:	3	
Volume of mixture in each over-the-road truck:	6,117	gallons
Weight of mixture in the over-the-road truck:	43,983	pounds
Number of over-the-road deliveries to the detector:	1,200	
Miles from Fermilab to Ash River	592	miles
Guess estimated Fuel Mileage for the Tractor-Trailer	8	mpg
Gallons of diesel fuel burned, one way	74	gallons

Use the truck scale at the Fermilab Receiving to weight the gross weight of the truck before and after filling with the mineral and pseudocumene mixture. Use this information to provide the quality assurance for the quantity of mixture shipped to the north.

Assume Duration (calendar months) of Oil Filling:	14	months
Assume this number of driving days per month:	20	days/mo.
Number of driving days to transport the full detector oil:	280	days
Number of truck loads leaving Fermilab per day	4.3	
Number of truck loads leaving Fermilab per week	21.4	
Ideal number or rail cars of mineral oil received per week	7.1	

More Questions:

11. Assume cleaned and insulated tanker trucks are used. Does one have to inspect the inside of the tanker prior to filling with the mixture?
12. Can the truck trailer tank be heated while underway?
13. If so, does one need to do anything special to ensure that the tank is heated during the transit time to the far detector?
14. Is it appropriate to car-seal the tank drains and vents after filling?
15. When a load arrives at the far detector, does one need to sample and re-test the mineral oil and pseudocumene mixture prior to off-loading to ensure that this delivery will not contaminate the existing inventory? Or if car-seals are used, is this sufficient?
16. Does it make sense to use dedicated tanker trailers to transport our mixtures to ensure purity? Since each truck then drives an additional eleven hours (~ 600 miles) empty, does this double our shipping costs? Are there other means of avoiding contamination from the tanker trailer that are standard industrial practice?
17. What is the appropriate level of spill containment at the Fermilab rail head where the mineral oil and pseudocumene rail cars are received? Is it necessary to pave the area and surround it with a low dike? See: http://www.containmentcorp.com/products/truck_train/rail_car/startrack.html for example spill containment. Does this meet the Spill containment that is required by the Spill Prevention Control & Countermeasures (SPCC) regulations?
18. What is the appropriate level of spill containment where the trailer trucks are filled? Assume that the trucks are filled at the rail head, adjacent to the tank car on the rail siding.

19. Is it necessary to include a platform with gangway to give the operators access to the top of the rail car to insert the load-out arm and to check the relief and vent valves, etc. Does this need to be under a roof? If under a roof, does this need to be partially or fully enclosed?
20. Does it make sense to perform this entire operation at a location closer to the far detector to reduce the trucking costs? Would Duluth Minnesota or Superior Wisconsin be a reasonable location?
21. Does it make better sense to empty the railcar contents into inter-modal shipping containers, truck the containers to a building at Fermilab, and perform the mixing and blending inside of a building? Would this lessen any spill containment or other infrastructure needed at the railhead?

Option # 2:
Follow the same logic and procedures as in option #1, but use tractor-trailer tankers in lieu of rail cars to receive the pseudocumene and mineral oil directly from the suppliers. Choose to perform the mixing and blending operations at Fermilab, perhaps in the Meson Detector Building, where the additional infrastructure needed for spill containment and loading arms can be minimized. To make this work efficiently, choose a location where two semi-trailer tankers (one with mineral oil, one with pseudocumene and waver shifters) can be positioned in close proximity to one and another.

Option # 3:
Follow the same logic and procedures as in option #1, but use rail cars to transport the mineral oil and pseudocumene mixture to a geographic location closer to the far detector location such as Duluth Minnesota or Superior Wisconsin. Then use a dedicated short haul trucking firm to transport the material to the detector. One could also consider using a rail siding nearer to the far detector such as the Casco, Brookston or Kelly Lake Minnesota stations (located along the BNSF main line, just south of Virginia). The BNSF also has right of way along the CN track heading north to International Falls. CN lists Orr Minnesota and several other small stops which appear quite closely located to the far detector location.

Option # 4:
Use the same logic and procedures as in options # 1 and #3 above, but use inter-modal shipments to transport shipping containers of mineral oil and pseudocumene mix from Chicago to Minneapolis MN. Use semi trucks from Minneapolis to the far detector. (The number of inter-modal terminals is limited). This is probably not cost competitive.